Optimal Sensor/ Actuator Locations for Active Structural Acoustic Control (ASAC)
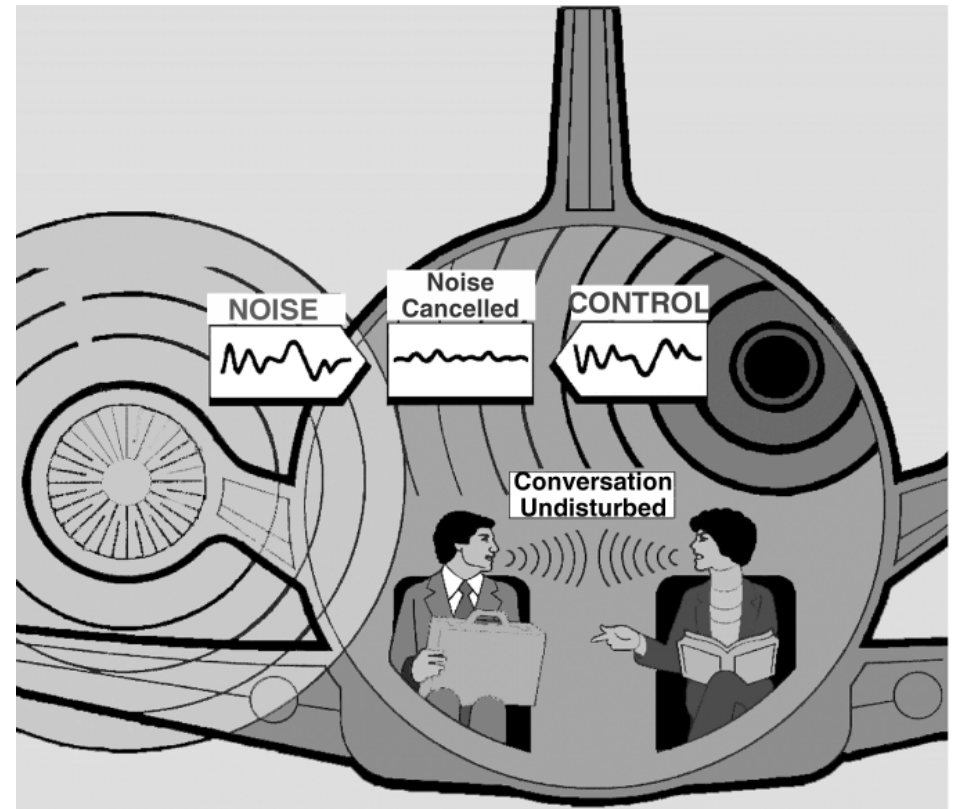
Sharon Padula, NASA Langley

Daniel Palumbo, NASA Langley

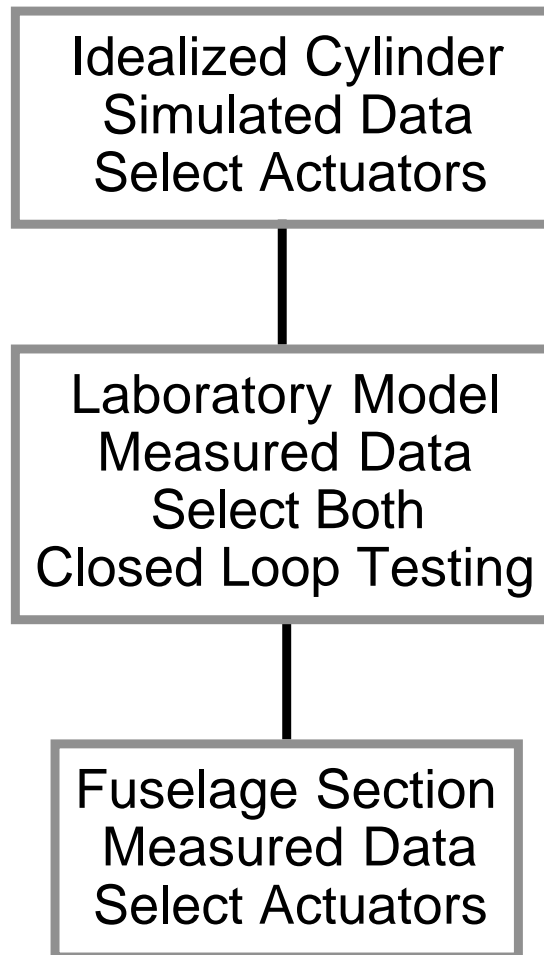**Rex Kincaid, William and Mary**

39th Structures, Dynamics and Materials Conference

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Background

- Noise inside the cabin is due to structural vibrations
- Primary source of vibration is jet or turboprop engine
- Active control uses secondary sources to cancel primary source
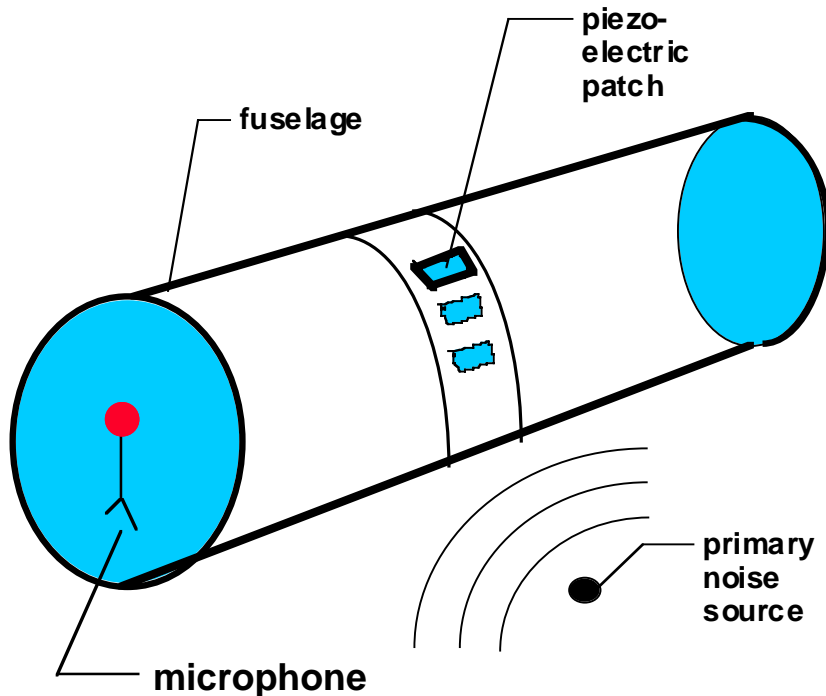- Location of actuators and sensors affects noise reduction

History of Sensor/Actuator Location Research

```
┌─────────────────────────┐
│   Idealized Cylinder     │
│   Simulated Data         │
│   Select Actuators       │
└─────────────────────────┘
             │
┌─────────────────────────┐
│   Laboratory Model       │
│   Measured Data          │
│   Select Both            │
│   Closed Loop Testing    │
└─────────────────────────┘
             │
┌─────────────────────────┐
│   Fuselage Section       │
│   Measured Data          │
│   Select Actuators       │
└─────────────────────────┘
```

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Outline

- Active Structural Acoustic Control
- Selecting Optimal Locations
- Idealized Cylinder
- Laboratory Tests
    - Composite Cylinder at Langley
    - Fuselage Acoustic Research Facility at Boeing
- Lessons Learned

Active Structural Acoustic Control (ASAC)

piezo-
electric
patch

fuselage

microphone

primary
noise
source

- Actuators: Piezoelectric patches bonded to fuselage
- Sensors: Microphones inside cabin
- Challenge: Best locations for actuators and sensors
- Goal: Global noise reduction

noise + antinoise = silence ??

Estimating ASAC Noise Reduction

$$\text{minimize} \quad \|Hc + p\|^2$$

antinoise — noise

- Estimate lower bound for noise reduction using linear control
- p_i - response at mic i due to primary source
- H_{ij} - response at mic i due to unit input at actuator j
- Unknown control inputs c_i
- H, c and p depend on actuator and sensor locations

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Selecting Good Locations

Combinatorial optimization problem

Pick the best subset from a large set of candidate locations

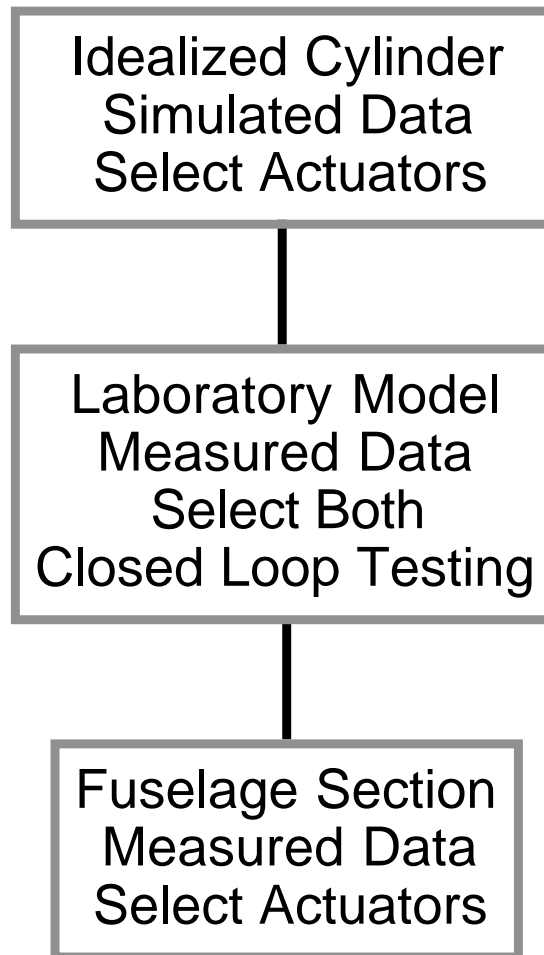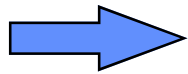## **Optimization methods**

Random Trials
Simulated Annealing
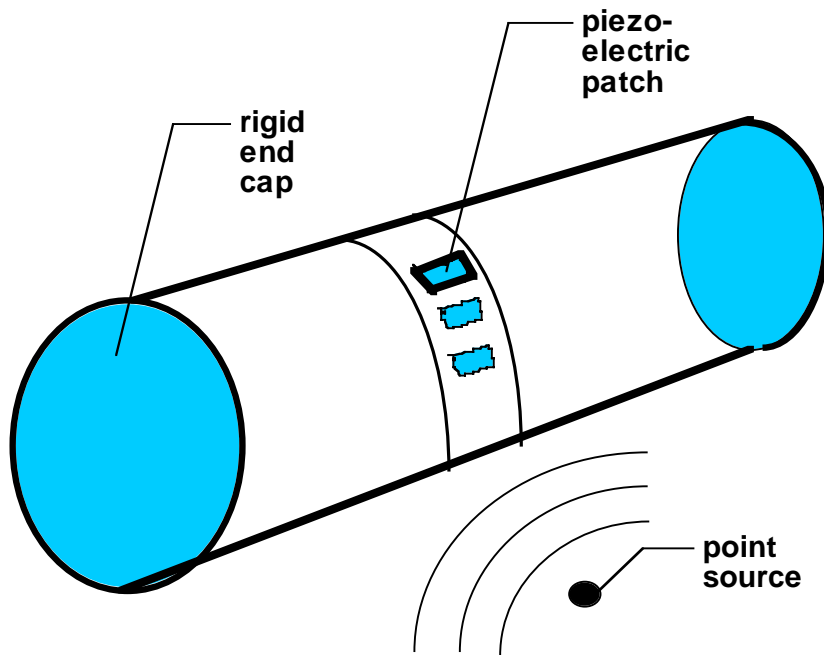Genetic Algorithms
Tabu Search

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Tabu Search

- Starts from randomly selected subset
- Uses search history as a guide
- Accepts both improving and nonimproving moves
  - Doesn't become trapped in local optima
- Searches the neighborhood
  - Move - Turning one location off and another on
  - Neighborhood - Collection of all possible moves
- Maintains tabu list
  - Does not allow a move which is on tabu list
  - Encourages exploration of new areas

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History of Sensor/Actuator Location Research

Idealized Cylinder
Simulated Data
Select Actuators

Laboratory Model
Measured Data
Select Both
Closed Loop Testing

Fuselage Section
Measured Data
Select Actuators

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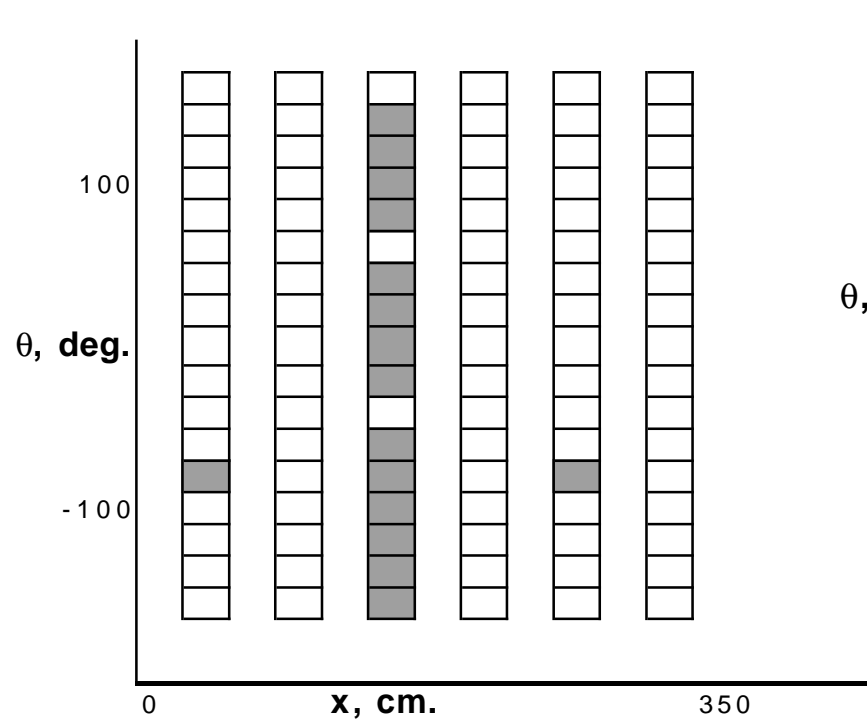
Simplified Example using Simulated Data

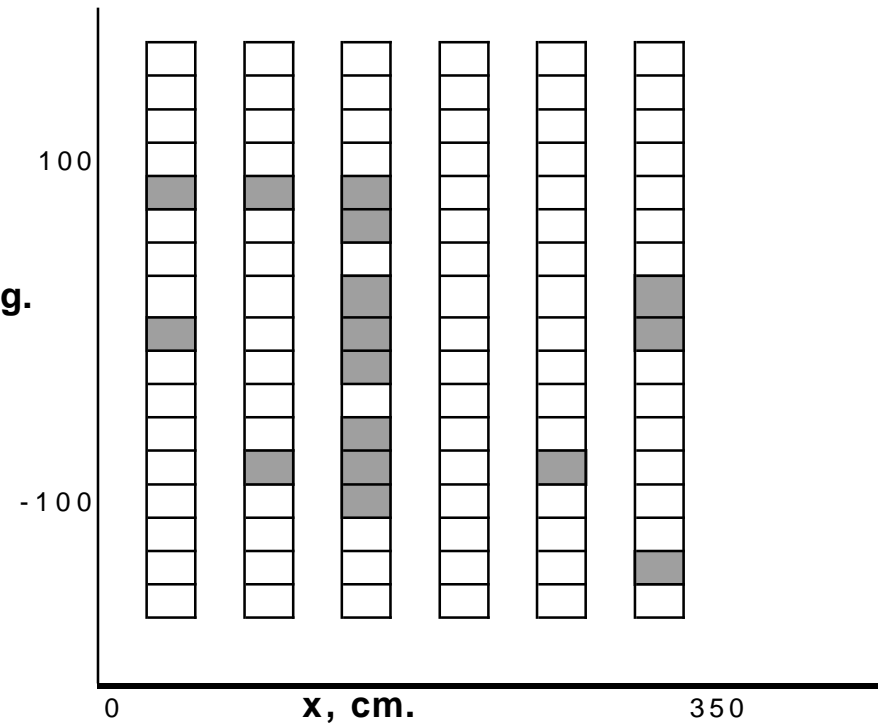**piezo-electric patch**

rigid end cap

- Use tabu search
- Select 16 of 102 actuator locations
- Minimize noise due to single frequency point source
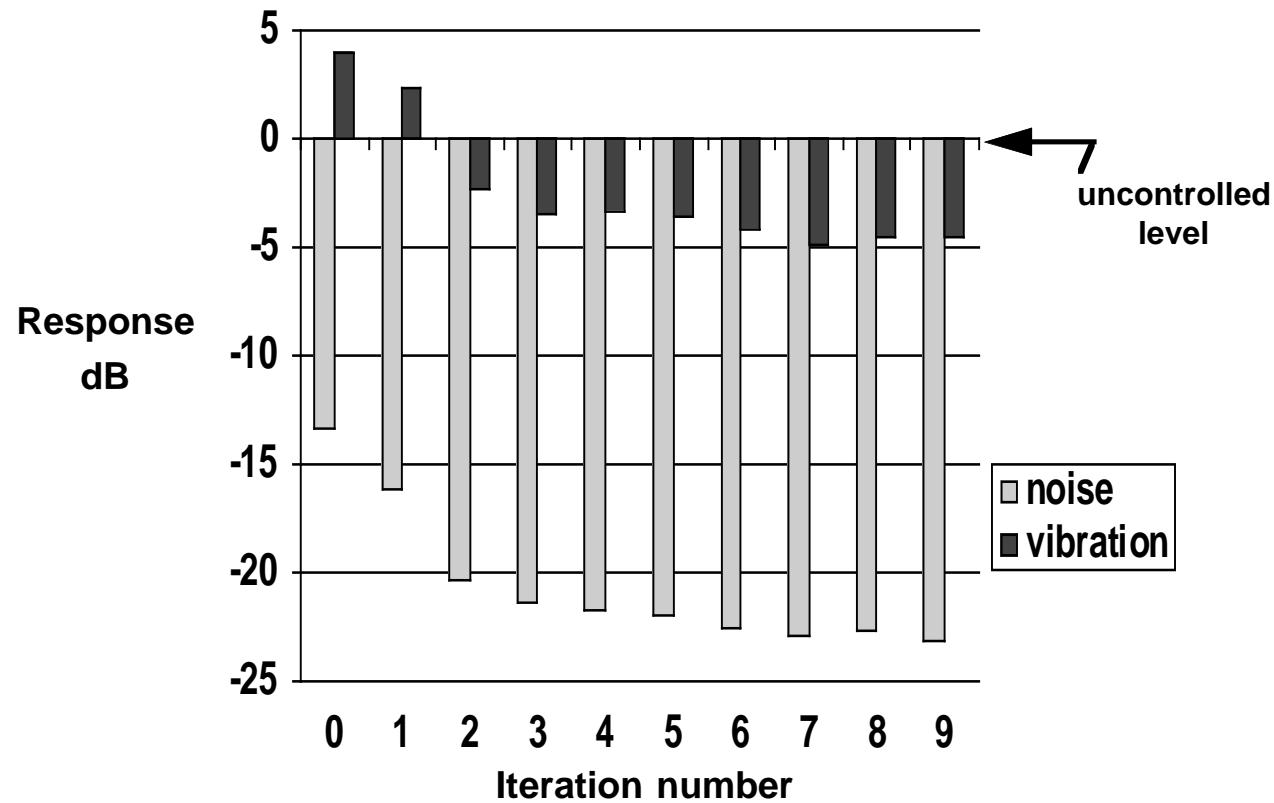- Predict noise and vibration using analytic functions

point source

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Best Actuator Locations

frequency = 200 Hz

frequency = 275 Hz

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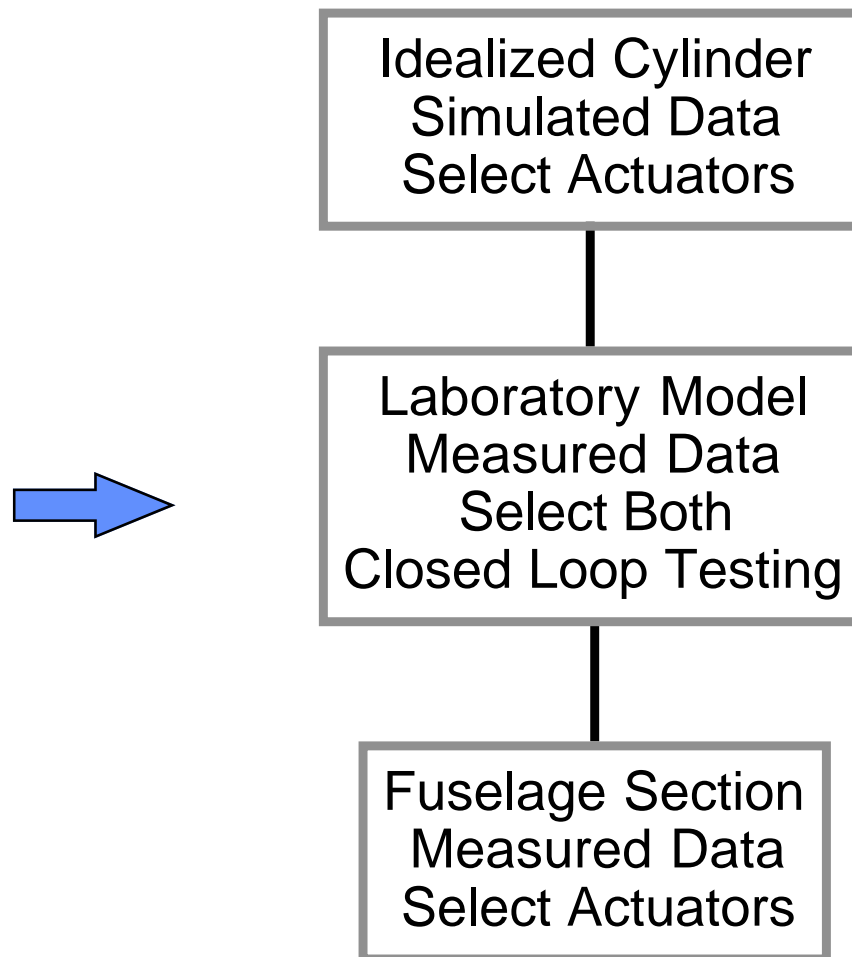
Best Locations Are Efficient Locations

note: Controlled response is compared to uncontrolled level

History of Sensor/Actuator Location Research

```
┌─────────────────────┐
│  Idealized Cylinder  │
│    Simulated Data    │
│   Select Actuators   │
└─────────────────────┘
           │
           │
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│    Measured Data     │
│   Select Actuators   │
└─────────────────────┘
```

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The Composite Fuselage Model

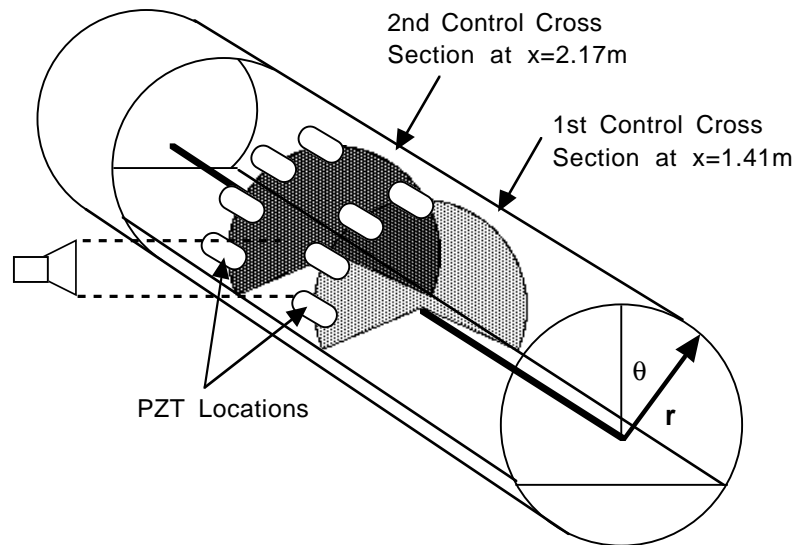2nd Control Cross Section at x=2.17m

1st Control Cross Section at x=1.41m

PZT Locations

θ

r
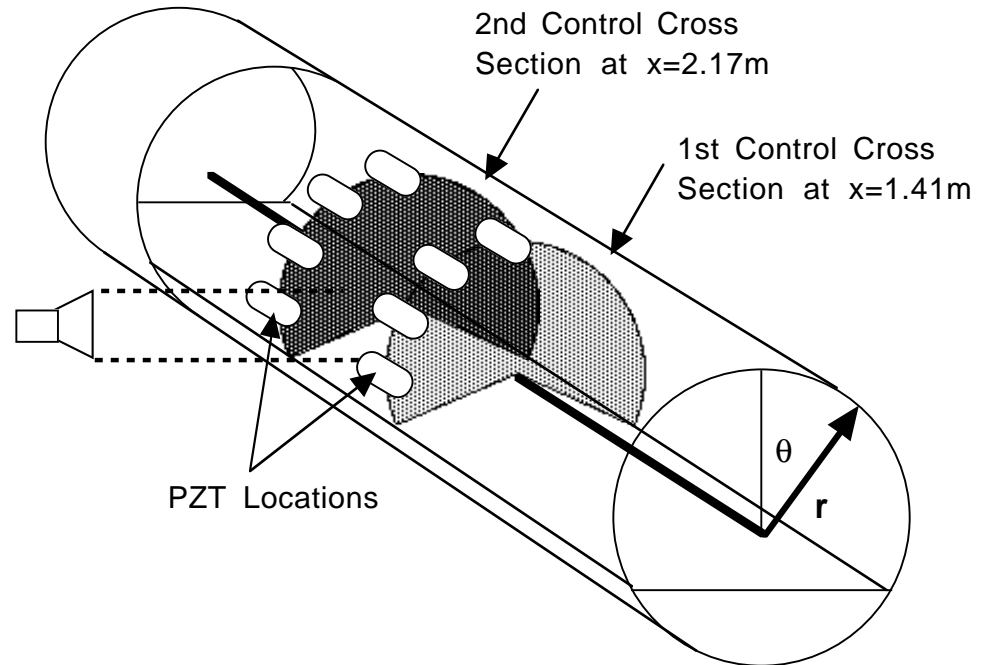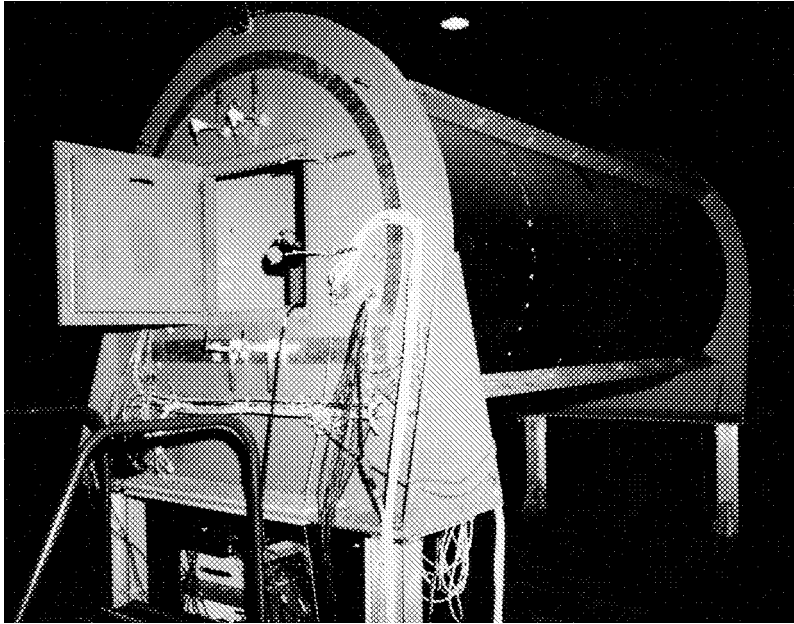
- Outer shell 9 layers of filament wound graphite epoxy, 1.7mm

- 3 Trim panels are honeycomb core with graphite epoxy skin, 7.35 mm total
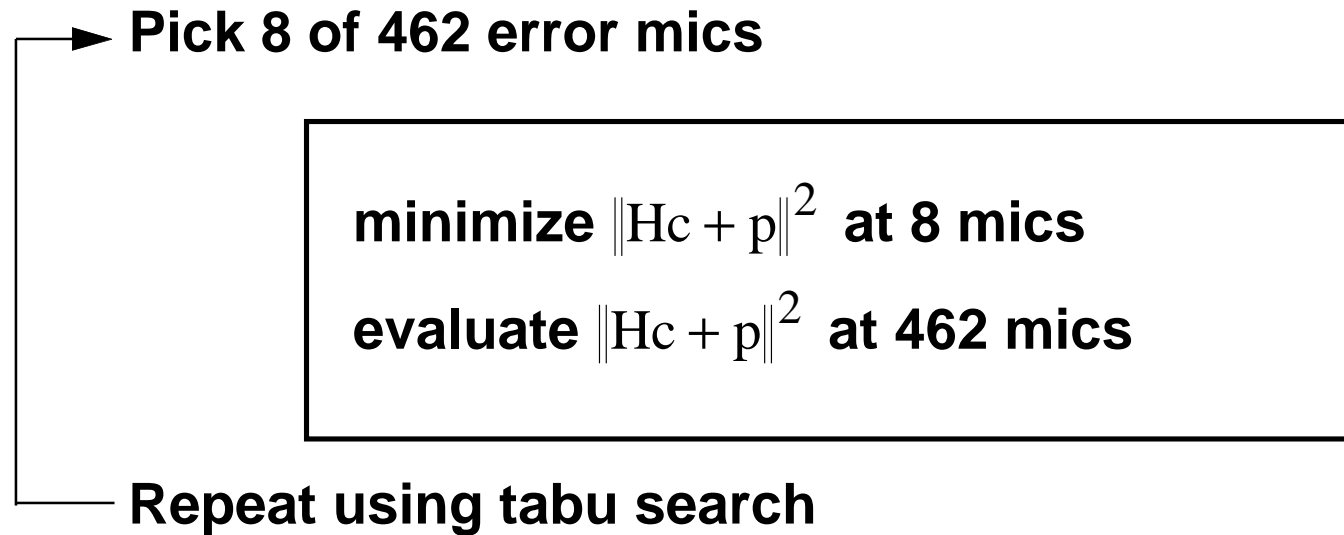
- Plywood floor, hard mounted to frame

- Eight PZT actuators bonded to inner surface of trim panels

- Boom with 6 mics sweeps interior for overall SPL

- 8 error mics placed on stands in interior volume

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Verification using Measured Data

2nd Control Cross
Section at x=2.17m

1st Control Cross
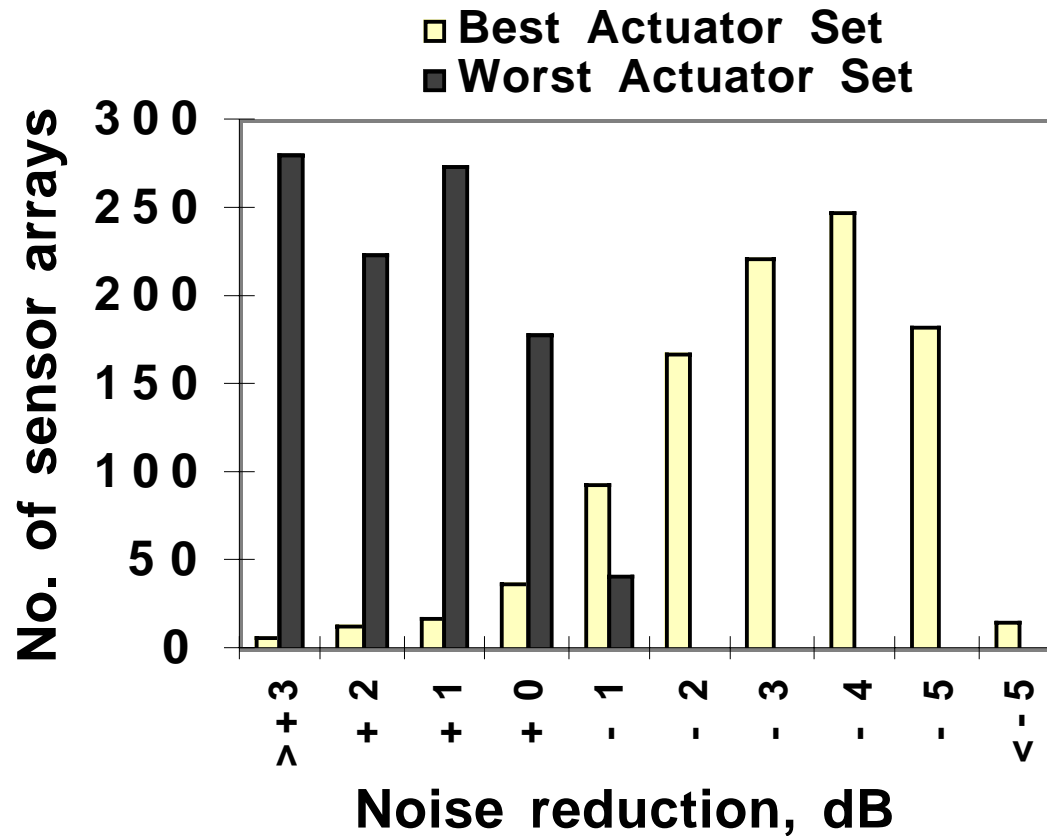Section at x=1.41m

PZT Locations

θ

r

- Actuators: Pick 4 out of 8
- Sensors: Pick 8 out of 462
- Goal: Reduce noise at 462 microphone locations
- Challenge: Does tabu search pick better locations than manual method?

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Tabu Search

Pick 8 of 462 error mics

$$\text{minimize } \|Hc + p\|^2 \text{ at 8 mics}$$

$$\text{evaluate } \|Hc + p\|^2 \text{ at 462 mics}$$

Repeat using tabu search

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Actuator/Sensor Location is Critical

note: relative noise levels compared to uncontrolled case

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Noise Reduction Results: Manual Method vs. Tabu Search

Selection Criteria	Predicted	Measured
Best 4 piezos **Best 8 sensors**	-5.7 dB	-3.9 dB
Worst 4 piezos **Best 8 sensors**	-0.5 dB	-0.4 dB
Manual Method	N/A	-2.7 dB

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History of Sensor/Actuator Location Research

Idealized Cylinder
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Select Both
Closed Loop Testing

Fuselage Section
Measured Data
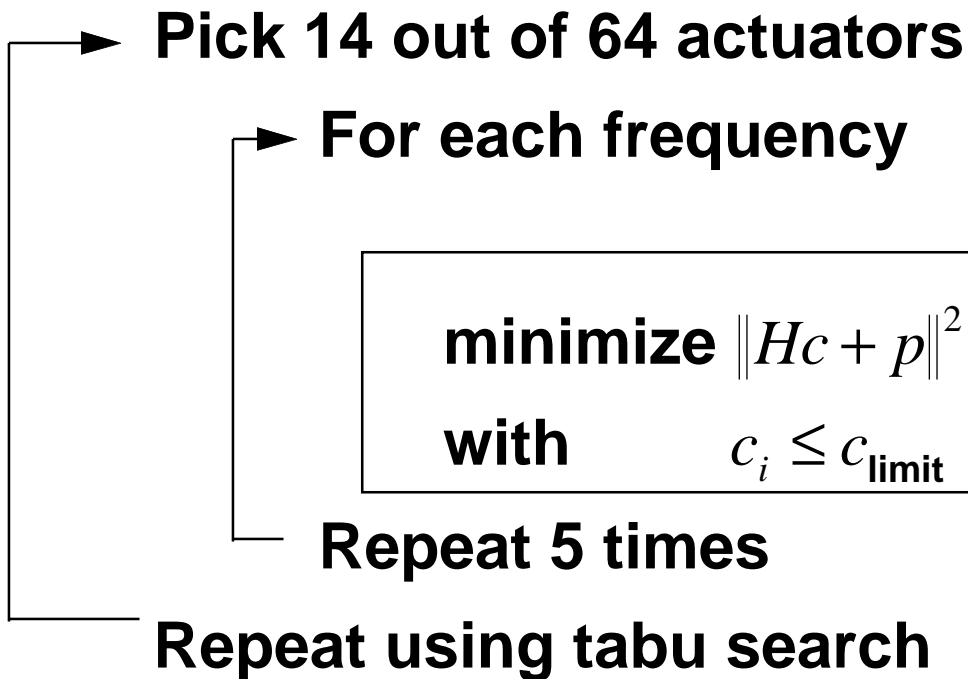**Select Actuators**

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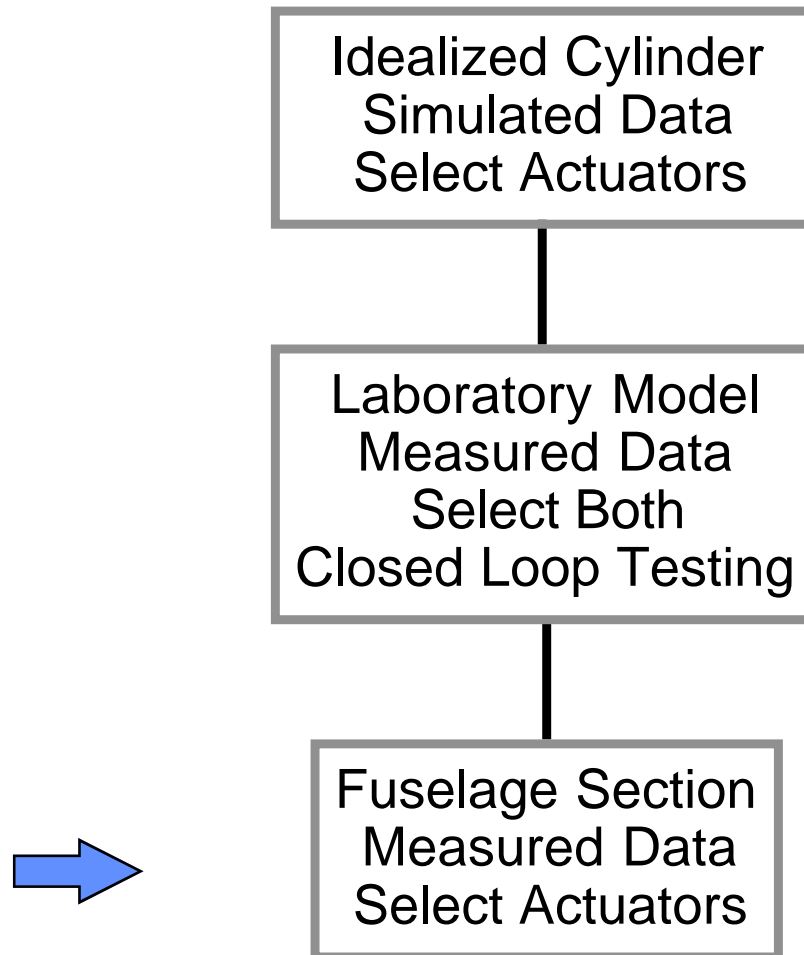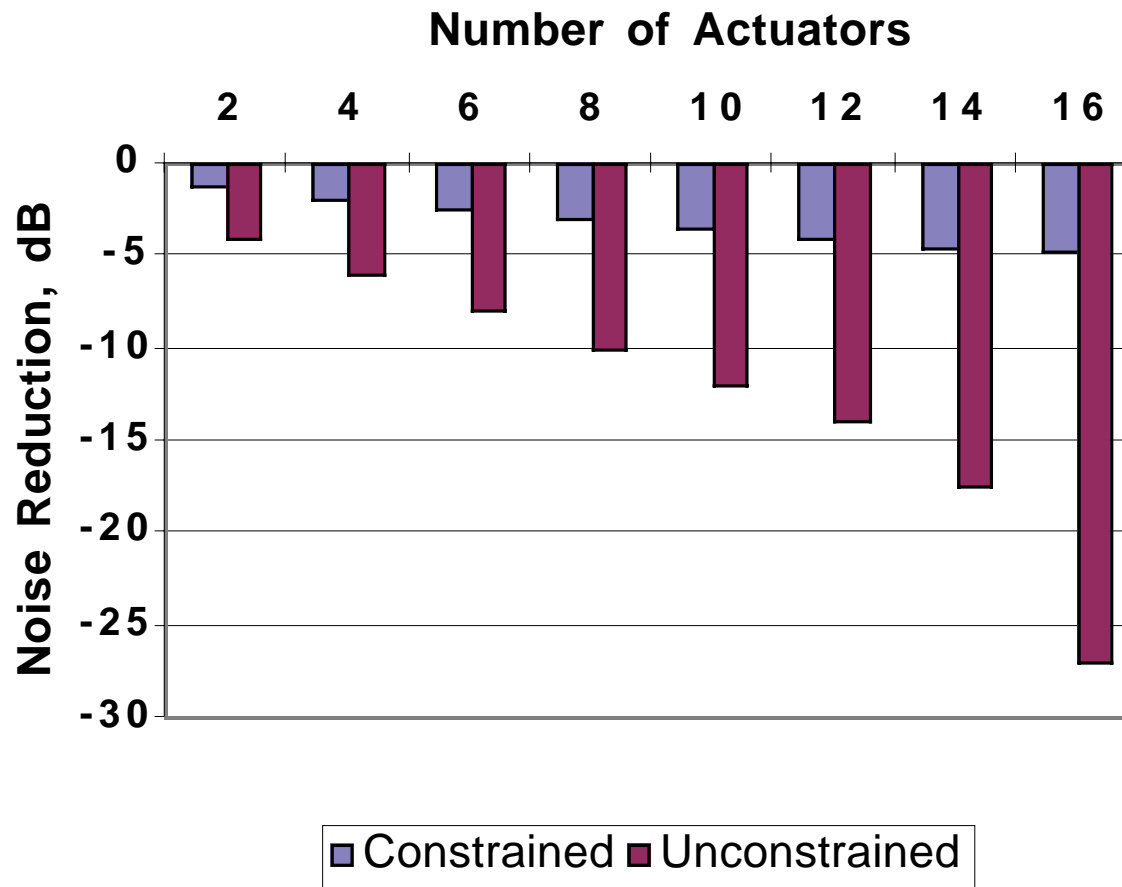
ASAC using Experimental Data
Fuselage Acoustic Research Facility (FARF)
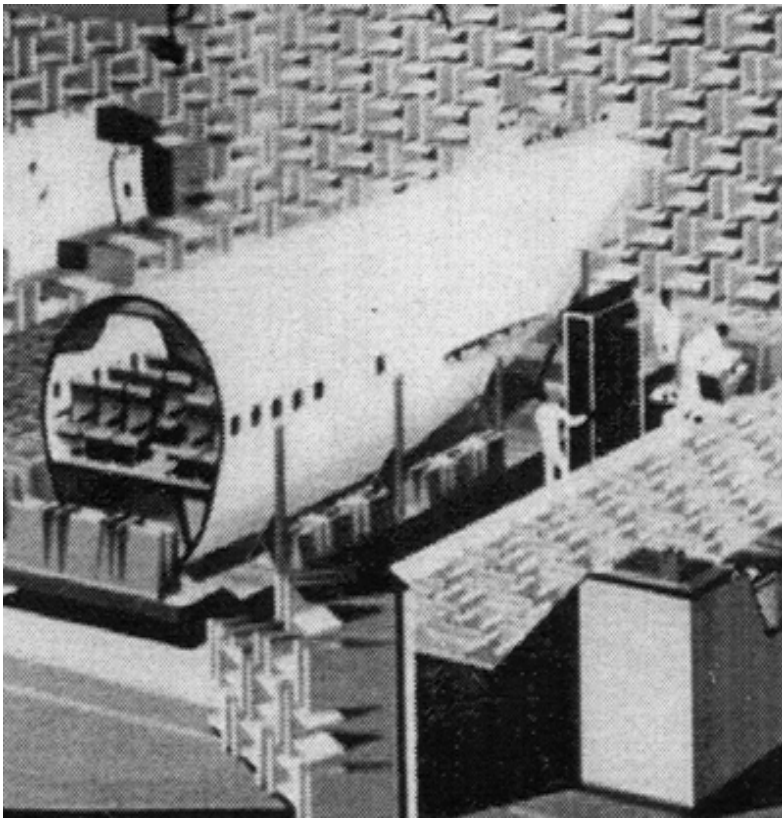
- Actuators: Pick 14 out of 64
- Sensors: 18 interior mics
- 5 targeted frequencies
- Force limits on actuators

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Modified Tabu Search

Pick 14 out of 64 actuators

For each frequency

$$\text{minimize } \|Hc + p\|^2$$

with $c_i \leq c_{\text{limit}}$

Repeat 5 times

Repeat using tabu search

Effect of Force Constraints

Number of Actuators

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Lessons Learned

- Actuator and sensor locations are important
- Tabu search automates the selection
- Tabu search depends on relative measures
- Approximate simulation of active controller may be adequate to pick good locations

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Summary

- Combinatorial optimization used to pick actuator and sensor locations

- Multiple acoustic source frequencies and actuator force limits added

- Application to Aeroelastic Control problems is under investigation

- Application to ASAC flight test is in progress

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